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POTENTIAL VALUES OF A SIMPLE BW PROTECTIVE MASK

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PREFACE

This paper was prepared in support of IDA's task entitled "Biological Warfare Defense Issues" sponsored by the Office of the Assistant Secretary of Defense for International Security Policy. Technical oversight of the study for the U.S. DoD was carried out by Ms. Lisa Bronson, Director of Negotiations and Implementations, and Mr. Paul Gebhard, Director of Policy Planning and Regional Security, both of the Office of the Deputy Assistant Secretary for Counterproliferation Policy.

This collaboration between U.S. and U.K. organizations was arranged informally by the authors. The pooling of information and the somewhat different perspectives on the issues involved allowed a better product than either organization could have created alone with equivalent total effort. We hope that others will be encouraged to create similar cooperative international arrangements for studying problems of mutual interest.

The authors greatly appreciate the helpful comments and assistance received during the development of this paper. Reviewers include Richard Aiken, John Bartlett, Lisa Bronson, Seth Carus, Marty Crumrine, Richard Danzig, Tom Dashiell, Paul Gebhard, Andy Hull, Chris Jehn, Barbara Johnson, Robert Kadlec, Edward Kerlin, Joshua Lederberg, William Patrick III, Brad Roberts, Douglas Schultz, Bernard Tucker, and Chris Whalley. Jeff Preston and Craig Colton of the 3M Company, and Michael Fuchs of UVEX, were helpful in obtaining information and samples of potentially suitable BW masks. Johnathan Wallis was most helpful in researching key background information and performing repeated calculations.

Finally, the authors note that the opinions expressed in this paper are their own, and are not necessarily endorsed by the organizations with which they are or have been affiliated.

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EXECUTIVE SUMMARY

The Persian Gulf War heightened awareness of the potential threat posed by biological weapons to our armed forces, and to the forces and civilian populations of allies. It reminded defense officials that BW could produce casualties comparable in number to those possible with nuclear weapons. The prospect of such high losses could lead regional governments to refuse to join us in defending important common interests.

This paper argues that a relatively simple oro-nasal mask is the key to effective protection against large-scale BW attack. To show the efficacy of such a mask, this paper compares the threat posed by the three classes of weapons of mass destruction: nuclear, biological, and chemical. This comparison demonstrates that for *unprotected* populations the threat of BW can be even greater than that posed by nuclear weapons, whereas for *protected* populations the BW threat can be made several orders of magnitude less than that posed by nuclear weapons.

Because less than ten kilograms of biological agent could devastate a target such as an unprotected city, the prospects of interdicting biological attacks before they can be delivered are poor. Similarly, while both pre- and post-exposure medications can offer some protection against some BW agents, they cannot provide reliable protection against the full range of potential agents.

The primary BW threat is attack through inhalation, as BW attacks aimed at infecting victims through the digestive tract or skin are less effective and can be countered by normal sanitation measures. Recognizing this, the paper explores the protective potential of simple oro-nasal dust masks. Masks that can reduce the potential effectiveness of BW agents by a factor of as much as 10,000 are available commercially, for less than $5 each. By providing protection, such masks would require an attacker seeking to devastate concentrations of population to deliver far higher amounts of BW agent—and therefore to use readily observable means of delivery. This can enable good use of active protection measures, such as air and missile defenses, or preemptive attacks to destroy BW capabilities before they can be launched toward their targets. Other synergistic effects are possible. For example, even partial protection could still reduce the concentrations of BW agents reaching victims to levels where medical treatment and the body's natural defenses can be more effective.

A variety of practical problems must be solved to realize the full protective potential of simple BW masks. For example, greater variations in size and shape are needed to allow a reliable fit for entire populations. Instruction and training would be needed. BW sensors to warn of attack would be important to allow populations to remove their masks when it is safe to do so.

In sum, simple masks appear to have the potential to dramatically suppress the danger of BW attack. The authors recommend that an aggressive program be created now to develop and exploit this potential.

I. INTRODUCTION

Proliferation of nuclear, biological, and chemical (NBC) weapons is a growing concern. Unless the spread of these weapons can somehow be halted, major changes will be required in allied defense strategy and capabilities. The risks and costs of defending vital interests will rise substantially. Correspondingly, the US, the UK, and their allies will find defense of their important interests more difficult and painful, and other states will become far less willing to support such defense efforts. Recognizing this, the allies are aggressively searching for more effective political means to halt NBC proliferation, and, to the extent it cannot be halted, for military and technical means to counter it.

Clearly these pursuits complement each other. Political measures can complicate, slow, and deter proliferation and strengthen the basis for international reaction when evidence of prohibited programs appears. Thus, they should reduce the number and scope of the NBC weapons programs to be countered, buy time to deploy countermeasures, and win domestic and international political support for difficult counterproliferation actions. At the same time, better means of countering NBC weapons should decrease demand for them by reducing their political and military utilities.

The purpose of this paper is to provide a broad perspective on the value of simple BW masks, particularly for civilians. We will argue that such masks are an essential ingredient of any strategy for countering BW proliferation, that history shows that populations are willing to take such unusual measures as wearing protective masks when a frightening disease threatens, and that masks may have the potential to prevent BW from becoming an even greater strategic threat than that posed by nuclear weapons.

Civilians are the primary focus for several reasons. NATO troops, at least if warned, have individual CW physical protection that protects against BW attacks as well. The US, UK and their allies depend on civilians in overseas theaters to operate the ports, airbases, and infrastructure upon which intervention forces would depend. The vulnerability of civilian populations to BW attack, both at home and in overseas countries, could lead governments to hesitate to support interventions against a state assessed to have a BW capability. Nonetheless, we will discuss the more direct values of simple BW masks for military forces in section VIII, below.

II. COMPARING THE THREATS POSED BY NUCLEAR, CHEMICAL, AND BIOLOGICAL WEAPONS

Nuclear, biological, and chemical weapons all have been described as "weapons of mass destruction." However, these three classes of weapons have very different potentials for causing mass destruction, and, in this respect, their proliferation should not be of equal concern. The most important measure of the difference in their potential to cause mass destruction is the *"residual threat"* they each pose after all practical countermeasures have been taken.

Nuclear weapons pose a high residual threat because the prospects of achieving a near-perfect defense against nuclear attack at reasonable cost seem poor, and the detonation of even a single nuclear weapon on an allied city or major military force would cause enormous numbers of casualties and great destruction.

Chemical weapons pose a substantially smaller residual threat. When used against concentrations of unprotected military or civilian personnel, they require considerably more weight on target to inflict the same numbers of casualties as would a single nuclear-armed missile. This implies that multiple delivery systems of substantial size must be used, providing opportunities for defenses to blunt a chemical attack, thus further raising the weight of attack needed to achieve nuclear-comparable results.

Additionally, a program of passive protection measures can substantially reduce the residual threat of chemical weapons. Given such a program, and assuming timely warning, civilians could remain in at least makeshift shelters, and, depending on the quality of the shelter, wear protective masks if needed. Causing large numbers of casualties among civilians *thus protected* would require far heavier quantities of agents in order to ensure that sufficient amounts of chemical agents to produce fatalities would penetrate through the protection of buildings and masks.

Military forces required to keep fighting also can be protected with masks, suits, CW detectors, antidotes, and decontamination. However, depending upon ambient temperature, training levels, required activities, and other factors, such protection can substantially reduce the efficiency of military personnel, thus requiring more time, personnel, or equipment to accomplish many military tasks. On balance, while the associated political, financial, and manpower costs would be substantial, the allies could configure their forces so that the casualties that could result from CW attacks by any foreseeable regional enemy would be minimal, and the forces could achieve their military

goals despite the burdens of chemical protection. Thus, the residual threat posed by CW is far smaller than that of nuclear weapons.

Biological weapons pose a particularly troubling threat. First, the weight of BW agent required for a devastating attack against an unprotected population is orders of magnitude less than that required for CW agents. Thus, BW attacks sufficient to destroy the populations of cities can be delivered by means that are extremely difficult to interdict. For example, a small drone could spray out as little as 6.5 kilograms (kg) of aerosolized anthrax in a crosswind line tens of kilometers upwind of a city. The resulting lethal cloud could drift over the city causing hundreds of thousands of deaths within as little as 48 to 72 hours. Such an attack would most likely be done at night so as to avoid the ultraviolet light of the sun, which kills most biological agents in a matter of hours.[1]

BW also is particularly troubling because, in a matter of a few weeks, easily acquired and innocent appearing facilities, equipment, and materials can allow the manufacture of sufficient quantities of biological agents to inflict massive casualties on unprotected populations. Thus, in the absence of comprehensive and intrusive monitoring arrangements, we have little chance of knowing whether a state is manufacturing a potentially devastating BW capability, of preventing its manufacture, or of destroying it by military means.

Taken together, these characteristics of biological weapons mean that it is extremely difficult to prevent a reasonably competent and determined opponent from delivering biological weapons against concentrations of personnel. Thus, *defense against a biological attack must emphasize protection of personnel jeopardized by agents arriving in their vicinities.* If this cannot be done well, biological weapons will pose a *residual threat* that is orders of magnitude greater than that posed by chemical or nuclear weapons. Worse yet, biological weapons using agents that are highly contagious, and for which US, UK, and their allies have no ready counters, may pose a global threat greater than posed by a large-scale nuclear war. The fundamental question is thus: how well can targets be protected from BW agents delivered into their immediate vicinities?

III. PROTECTING AGAINST BW ATTACKS AT THE TARGET

A. Vaccines

In concept, the most attractive defense against BW attack would be to develop inexpensive and effective oral vaccines to protect target populations. In fact, vaccines against some potential BW agents exist, and some of these vaccines have been

stockpiled. Further, extensive research is being done to develop new vaccines against additional potential BW agents. Vaccines cannot be the complete answer, however, for a variety of reasons.

First, vaccines do not exist for a number of diseases that are considered usable for biological warfare. In addition, new strains of naturally occurring diseases can appear from time to time, either as natural mutations of the older variants of the disease, or as the result of efforts to create new BW agents. Available vaccines may be ineffective against these new strains.

Second, even where vaccines do exist against a disease, they may not be effective when victims are exposed to the disease in the unnatural ways that typify biological warfare. For example, some plague vaccines are generally ineffective when the disease is introduced into the body via inhalation of an aerosol rather than via flea bites. In addition, vaccines that are capable of countering agents introduced into the body in quantities typical of natural disease transmission can be overwhelmed by the far larger concentrations that may be delivered in BW attacks. Vaccines also have other limitations that can reduce their potential utility. They usually have to be administered well in advance of potential exposure, can require multiple boosters over a period of weeks to become fully effective, can cause adverse reactions in some recipients, can fail to be effective for others, and can be costly.

Third, it can be difficult to anticipate what diseases to vaccinate for. Vaccinating for several diseases to hedge against such uncertainties is more expensive, although polyvalent vaccines are being developed. In addition, the effects of multiple simultaneous vaccinations could cause problems, especially for the very young or the old.

Despite these limitations, vaccines can play an important role in defending against BW at the target. They can save potential victims who have not received overwhelming doses of the agent they protect against. They can undercut the effectiveness of an opponent's BW attack capabilities, perhaps dissuading BW use in wartime, or increasing the difficulty of creating an effective BW threat in peacetime. Vaccines can also help to maintain the confidence of those who might be at the greatest risk of being attacked.

In summary, though vaccines can play an important complementary role in defending against BW, they cannot be the complete answer. Thus, while development of improved vaccines should be pursued, other protective measures are clearly needed.

B. POST-EXPOSURE MEDICATION

Antibiotics, antidotes, and antitoxins are another important way to limit the effects of a BW attack, but they too leave significant gaps. Effective post-exposure medications have not yet been found for some known BW agents. In addition, some diseases for which otherwise suitable post-exposure medications exist cannot be treated effectively once they have progressed far enough to present physical symptoms.

Even when effective medications exist, and when the appearance of symptoms does not imply an already irreversible situation, proper and timely diagnosis may not be possible. Because some diseases have similar symptoms at onset, diagnosis can easily be confused until the disease worsens or blood tests can be completed. Simultaneous use of more than one agent can also confuse diagnosis. Confused diagnoses, or the use of multiple agents, can cause major problems when the drugs needed to treat one possible disease are incompatible with those needed to treat another.

As with vaccines, massive doses of BW agents can overwhelm treatment by otherwise effective medications. In addition, poorly controlled use of antibiotics can lead to the appearance of resistant disease strains. Finally, the vast numbers of people that could be simultaneously exposed to a BW attack, whether actually affected or not, could exceed the maximum practical capabilities of emergency medical treatment facilities, diagnostic laboratories, testing materials, and stocks of drugs. Clearly, something more is needed to prevent these capabilities from becoming swamped.

C. Simple Protective Masks

A particularly promising additional protective measure is a face mask, *since the only practical way to cause mass casualties with BW is to use agents that attack through the respiratory system*. Introducing BW agents via the digestive system is not practical, provided foods are reasonably carefully prepared, and the water supply is protected by a modern purification system or is sterilized by boiling or with chemicals. A few toxins are known to attack through the skin; an example is "T-2," one of the many varieties of tricothecene mycotoxins. Such materials are not attractive as weapons of mass destruction however, as large amounts are required to produce lethal effects. In addition, simply washing the skin provides effective decontamination. Thus, the principal risks arising from BW attack are from agents that attack through the respiratory system.[2]

Masks that can protect against BW attacks through the human respiratory system can be far simpler, cheaper, and less burdensome than those required to protect against

chemical agents. This is because filters that can remove biological warfare agent particles from the air are far easier to design and manufacture than the kinds of filters needed to remove CW agents. [3]

As the CW protection that is provided to many armed forces protects against BW attacks as well, a simple BW mask has two primary values: 1) its potential to protect civilians from BW attacks, and, 2) its potential for use by troops to avoid the larger burdens of wearing the CW mask, when chemical attack can be safely ruled out. Note that a given weight of BW attack can cover far larger areas with lethal concentrations of agent, thus requiring much greater numbers of personnel to wear their CW masks and accept the associated burdens. The next several sections concentrate on the use of simple BW masks by civilians; their potential value to military personnel is discussed later.

Clearly, if a cheap and sufficiently effective BW mask can be provided to civilians, it should be possible to reduce the residual threat posed by BW attacks well below that posed by nuclear weapons. The question is whether it is practical to equip large numbers of civilians with such masks, and whether such protection can be expected to have the desired effects.

IV. AVAILABILITY OF SIMPLE BW PROTECTIVE MASKS

Masks that can provide the necessary high levels of protection against BW attack are already available commercially. These masks are commonly used to protect workers in dusty environments containing radioactive or otherwise harmful particles. They are also sold in hardware stores for household use, and are effective in protecting hospital staff from diseases spread by sneezes.

In fact, during preparations for Operation Desert Storm, the Chemical and Biological Defense Establishment of the United Kingdom tested a simple dust mask available on the European market. This mask, which cost the government less than $4, allowed leakage of only 0.2% of the 1- to 5-micron-sized particles that would present a hazard in the event of BW attack. A higher quality, but approximately equal cost mask made for the US market limited penetration to only 0.01% of the 0.8-micron-sized particles in the outside atmosphere, implying even greater efficiency for larger particles in the 1- to 5-micron range.[4,5] In fact, a number of manufacturers and a variety of different masks are available to choose from.

The achievement of such limited penetration requires careful fitting of the mask, particularly around the nose. In the assessments provided below, we assume that any

civilians to be protected would be provided at least with clear written instructions on how to adjust and test the fits of their masks. We also assume a leakage rate of 0.1%, which is slightly better than the rate for the poorer of the two masks mentioned above. Further comments on how to achieve good mask fits are provided in section VII, below.

V. GAUGING THE RESIDUAL THREAT POSED BY BW WHEN MASKS ARE AVAILABLE

To gauge the residual threat posed by biological weapons, one must first ask what it is about nuclear, biological, and chemical weapons that makes them weapons of mass destruction. As outlined in the arguments presented in section II above, we believe that a very good measure of the ability of these weapons to cause mass destruction is the *reciprocal of the weight or volume of material that must be delivered in the vicinity of the target* to cause devastating effects. The value of this measure can be illustrated by considering two extreme examples. If a pinch of some kind of dust thrown into the air inside a city would kill most of its inhabitants, the destruction of a city could be simply a matter of choice for an attacker. But, if destruction of the city were to require the equivalent of a supertanker of some kind of fluid to be sprayed over it, defense of the city should be a tractable problem. Note that, in the former case, the reciprocal of the weight, our measure of mass destruction potential, is many orders of magnitude greater than in the latter.

To assess the effects of masks and other protective measures on the *residual threat* posed by BW, we must estimate how much more agent would have to be put into the environment in order to ensure that sufficient amounts would penetrate through the protection of buildings, masks, and any other protective "filters" to be deadly.

As a specific example, section II stated that an unprotected city could be poisoned effectively with as little as 6.5 kg of aerosolized anthrax. If its population were equipped with masks of the kind mentioned in section IV (0.1% leakage or less) and could use them effectively (a matter to be discussed further below), the density of agent in the surrounding atmosphere would have to be raised by a factor of at least 1,000 to make the atmosphere reaching the nose and mouth as deadly as without masks.. To a first approximation, this would require attacking the city with at least 1,000 times as much agent, or, in this case, at least 6500 kg of anthrax.

Similarly, if the population of the target city were to shelter themselves in interior rooms whose doors were sealed with sticky tape, the amount of agent penetrating to potential victims would be reduced by at least another factor of 10.[6] In this case, the

total weight of anthrax that would have to be launched at the target city to effectively destroy its population would become at least 65,000 kg.

Covert delivery of attacks of this weight is impractical. Instead, substantial and readily detectable delivery vehicles would be required. The numbers of such delivery vehicles could be raised yet further by defenses deployed by the allies. If, for example, missiles had to be employed to deliver the 65,000-kg anthrax attack postulated above, and an ATBM system that could limit the number of missiles reaching the target city to 10% were present, then at least 650,000 kg of anthrax payload would have to be launched by the attacker. Launching this amount of payload at a target city would require the equivalent of more than 3250 SCUD missiles, an absurd proposition. [7]

Finally, an opponent's preparations for attacks of even a small fraction of this magnitude would surely provide warning signs far easier to detect than those associated with BW attacks of the minute size needed when a target has not been protected. Such warning signs should enable more effective and timely political and military actions to blunt the impending BW attacks.

Implementing any of these defenses would take considerable preparatory effort. It would also require the deployment of detection systems and the adoption of well understood means of warning target populations that BW attacks were imminent. Neither civilian populations nor military personnel can be expected to remain in shelters or to wear protective masks all the time.

In sum, protecting against BW at the target with simple masks and shelters can set up opportunities for other protective measures to become more effective. Warning, masks, and shelters force the BW attacker to deliver agent in amounts where detection would be likely and active defenses and prelaunch attacks could be effective. Additionally, even where masks and shelters do not totally prevent exposure to BW agents, they can reduce exposure below the levels at which vaccines would be overwhelmed, to levels more typical of natural exposure to disease, and for which currently available vaccines have been designed.

Finally, while practical considerations are likely to limit achievable total protection factors to values below the total of 100,000 suggested in the above example, substantially smaller protection factors can go a long way to reduce the residual threat posed by BW. The point is that the danger from BW attack can be massively undermined by relatively practical measures. In fact, the comparisons presented below indicate that the threat posed by BW is more responsive to simple protective measures than the threat

posed by chemical weapons, and vastly more responsive to protection measures than the threat posed by nuclear weapons.

VI. COMPARING THE RESIDUAL THREATS POSED BY NBC WEAPONS

We can estimate the relative magnitudes of the *raw* threats presented by nuclear, biological, and chemical weapons by calculating the reciprocal of the payload weights that would have to be launched against an *unprotected* city to cause as many deaths as would a single one-megaton-yield nuclear weapon. Our calculations of such estimates are explained in notes 1,8, and 9 at the end of this paper. These raw threat estimates for each class of weapon are shown by the three bars on the left in Figure 1, below. The *residual* threats posed to a city protected by active defenses in all three cases, and by masks and shelters against CW and BW, are shown on the right.

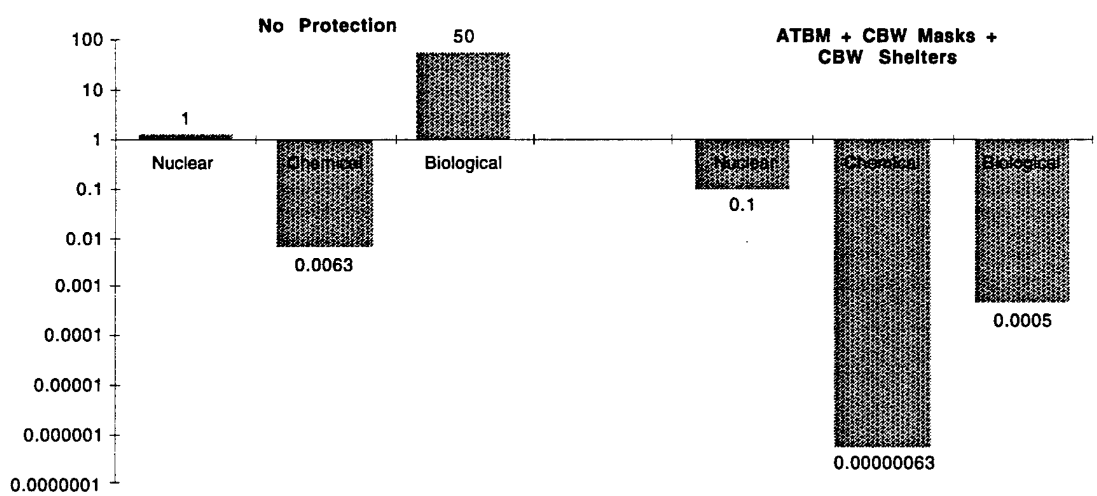

Figure. 1 Estimated Relative Magnitude of Threats Posed to Civilians by Nuclear, Chemical, and Biological Weapons

It should be noted that these are point estimates only, and are clearly subject to many uncertainties. Nevertheless, the *differences* in relative sizes of the raw and residual threats posed by the three types of weapons are of the right order of magnitude. It can be seen clearly that the combination of active defenses, simple protective masks, and shelters reduces the BW threat by 5 orders of magnitude, at least 3 of which come from the mask, 1 from sheltering within buildings, and 1 from the assumed missile defense. Thus, the threat of BW attack drops from approximately 50 times that posed by a nuclear weapon against an *unprotected* city to 5 ten-thousandths of the threat posed by a nuclear weapon against a *protected* city.

Alternatively, one can compare the residual to the raw threats posed by BW and nuclear weapons, respectively. In this example, the BW threat is at least 4 orders of magnitude more responsive to the defenses that can be deployed against it than the nuclear threat is to the single type of protection that can be deployed against it, active defenses. In other words, *efforts to protect populations from BW attack will be rewarded far more readily than those made to protect them from nuclear attack.*

VII. SOME PRACTICAL QUESTIONS

Some practical questions must be answered to assess the potential strategic benefits of a simple BW mask. First, *are such masks affordable* for states or regions that could be subject to BW attack? While the defense expenditures of some states and populations are very small, the general answer to this question has to be yes. For example, the entire urban populations of Saudi Arabia, Syria, and Israel (approximately 24 million) could have been equipped with such masks during Operation Desert Shield for $90 to 100 million. This is roughly the price of three of the several thousand tactical aircraft involved in Operation Desert Storm.

If the citizens are to be spared the necessity of wearing their masks as continuously as possible during periods when the potential for BW attacks is high, sensors to provide warning of actual attacks would also have to be purchased. Several millions of dollars more might be required for each concentration of population to be provided with warning of a large-scale attack.

Producing and procuring large numbers of masks for stockpile could reduce their costs. Even guaranteeing that masks would be quickly available for sale would be useful. A manufacturer should be willing to maintain an extra inventory of in-production commercial masks for not much more than the cost of the capital thus tied up. At the current prime rate, the interest cost on the $90 to 100 million in capital tied up in the example inventory of 24 million masks mentioned above would come to less than $10 million per year.

A second practical question is, *would target populations be willing to wear such masks?* Populations at risk to BW attack would have to be given warning of the possibility of such attacks, and encouraged to wear masks as much as possible during periods of danger. The kinds of masks required to provide good protection against BW agents are not significantly burdensome to wear, and the potential dangers of not wearing a mask could be made known.

While the absence of large-scale chemical attacks in the World War II eventually led to a relaxed attitude toward CW protection, urban populations in Britain and a few other countries were issued chemical protective masks; many carried them around during the early years of the war. Both Sweden and Switzerland have policies of providing total defense for their populations, which includes programs aimed at providing practical protective measures against nuclear, biological, and chemical weapons. In particular, Swiss homes have shelters provided with filtration systems, and the head of household is provided with a personal respirator, in his capacity as a member of the Swiss Armed Forces.

Israel also has a well-developed program for protecting its citizens with masks. A variety of models are available to allow protection for all citizens including infants, small children, the aged and infirm, and special cases such as those who insist on retaining beards that prevent effective use of the simplest types of masks. Excellent manuals describing proper mask use are available to Israeli citizens.[10] New masks employing lightweight air pumps to provide breathing air under positive pressure are also being developed. These will essentially eliminate the risk of poor fits that allow agents to leak into the masks. They will also eliminate the psychological burden felt when wearing current types of masks that require noticeable effort to draw in air. This Israeli program reflects widespread willingness of the citizens to make use of CW civil defense measures. Substantial numbers of urban Israelis wore relatively burdensome CW masks as a precaution against the possibility that Iraqi missiles fired at them during Operation Desert Storm were armed with CW warheads.

Today, citizens in some countries already make a habit of wearing "courtesy masks" in crowds, masks that are generally similar to those referred to in section IV, above. The wearing of such masks is becoming more common and acceptable in areas that have high concentrations of smog, such as Japan and southern California. Further, masks of the type needed are commonly sold in hardware stores for use when working in dusty or chemically contaminated environments. Finally, Indian citizens frightened by the apparent breakout in 1994 of pneumonic plague in their country wore scarves over their faces, and Indian street vendors did substantial business selling a variety of commercial dust and surgical masks.[11]

Even if entire target populations could not be counted on to wear masks during a BW attack, their ready access to masks could help discourage a BW attack. Small initial attacks should have less than strategic effects, and would drive the surviving target populations to wear their masks, thus undercutting the effectiveness of later attacks. This

could eliminate an aggressor's option to make graduated, but politically effective use of BW to force the allies to give up their intervention plans and disengage. If an aggressor launched large-scale surprise BW attacks to cause massive casualties, the allies might be lead to raise their war aims beyond the stakes that the aggressor intended to risk in order to win the issue at hand.

Achieving and maintaining a good fit is a requirement for obtaining the mask effectiveness projected above. One of the masks mentioned in section IV comes in two sizes and has been determined to fit 95 percent of the population well enough to prevent them from smelling samples of a test aerosol. Additional sizes and instruction on how to achieve a good fit would be necessary. Beards will prevent a good fit, requiring that they be shaved off, or that a more complex protective hood be worn. (Such hoods are also already available commercially.) Because large-scale BW attacks are most likely to take place at night, the mask must remain well fitted while sleeping. This might require better positioning straps or other means for helping the mask to remain in place.

There are other practical problems to be solved. For example, masks are not a practical solution for infants, who require other protective measures such as confinement to a room provided with filtered air, or the use of crib covers fitted with filter material. In addition, means must be found for expeditiously distributing masks and other protective equipment when the potential for BW attacks arises. In addition, recipients must be instructed on their use. Further, political constraints may prevent distribution of masks and instruction in their use much in advance of need. [12,13]

VIII. POTENTIAL MILITARY AND OTHER VALUES OF A SIMPLE BW PROTECTIVE MASK

A simple BW mask also could be useful to military forces. Because BW agents are so much more toxic than CW agents, far larger areas can be made hazardous with a given amount of agent. Further, greater toxicity allows a wider variety of ways to expose forces to BW attack. This implies that an opponent would find it far easier to impose some burden of protection and risk on large numbers of forces with BW agents than with CW agents, thus increasing the value of equipping them with less burdensome BW masks. The British Army followed an analogous policy of providing simpler, less burdensome partial protection against CW for its troops. This took the form of a facelet that provided useful protection against CW agents. It was worn continuously, whenever there was a potential risk of CW being used, and provided protection until respirators could be donned for full protection.

Thus, even forces equipped with CW protection may find it useful to carry BW masks, which are relatively light and substantially less burdensome to use than the standard CW mask. Certainly sleeping in a simple BW mask would be far more restful than sleeping in the standard CW mask. The standard US CW mask, for example, can be very hot because it covers most of the head with air-impermeable material.

A specialized BW mask also could reduce the penalties to allied forces of not yet having a BW detector with the broad capabilities currently sought. Low-burden BW masks could be donned whenever suspicious levels of dangerously sized particles were detected in the atmosphere. The delays currently needed to determine the exact nature of such particles would then be more tolerable.

Stocks of rapidly transportable simple BW masks also could be maintained as a means of coping with a BW terrorist campaign. Masks may be particularly effective in this case, because the volumes and concentrations of BW agents employed may not be as high as those that a better equipped regular military opponent could deliver. Certainly, in the aftermath of the first attack, populations would be anxious to protect themselves.

Even more generally, BW masks can be a powerful tool for limiting the spread of contagious diseases, whether the product of human mischief or not. They can block what is far and away the most dangerous means of transmission—the breathing of air contaminated by the sneezes and coughs of the infected.

Finally, to the extent that a simple mask can prevent BW from emerging as a threat comparable to or even greater than that posed by nuclear weapons, it could render moot the question of whether the US needs to consider nuclear retaliation as a deterrent to large-scale use of BW.

IX. ADDITIONAL CAUTIONS

While a simple BW mask may play a very important role in reducing the threat of biological warfare, it is not a complete and final answer for a variety of reasons. For example, advances in biotechnology may open the possibility for practical BW agents that can attack through the skin, or present other challenges.

Further, even with a very well implemented program to protect populations and forces from BW attack, a large-scale BW attack can cause great suffering to a state that experienced it. For example, a city of a million inhabitants that had adopted a BW defense strong enough to save 95% of its population would sustain 50,000 casualties. Still, while a potential calamity of this magnitude would be a serious consideration in any

leader's assessments, it is not nearly as disastrous as the potential death of most or all of a state's urban citizens.

Finally, the foregoing analysis shows that masks provide the most effective defense against BW by working synergistically with other protective measures, including warning systems, shelters, vaccines, and active defenses. Thus, a mask program should supplement, not replace, other measures to blunt the potential of BW attacks.

X. FINAL OBSERVATIONS AND CONCLUSIONS

This short discussion indicates that a simple BW mask appears to have considerable promise as a tool for keeping the threat of biological warfare from rivaling or exceeding that posed by nuclear weapons. Consequently, an aggressive program to exploit its potential seems appropriate.

Where the primary responsibility should lie for pursuing this kind of BW "civil defense" capability is an important issue. Responsibility for civil defense of the US has been managed by the Federal Emergency Management Agency. The US Department of Health and Human Services and some of its subordinate agencies, such as the Centers for Disease Control, should have an interest in the potential of a mask program to supplement other measures for controlling the outbreaks of epidemics. Certainly, the US Defense Department should be responsible for any program to supplement current CW defense for its personnel with a specialized BW mask, as well as for contingency programs to help protect future coalition partners from BW attack. In sum, a program to improve BW defense with a simple mask would cut across the responsibilities of many parts of the US government.

Still, unless specific responsibilities for exploring the potential contribution of a simple BW mask are assigned to some specific agency, it is unlikely to get serious attention. Given the broader BW expertise of the Department of Defense, and the near-term potential for BW to have strategic effects on US decisions to intervene with military forces overseas, there appears to be a good case for assigning to the DoD the lead responsibility for a program to aggressively develop and exploit the potential of a simple BW mask.

Finally, it may be useful to look from a longer historical perspective at the question of controlling disease epidemics.[14] Epidemics have cut wide swaths through humanity for thousands of years. They have come about as a result of contacts between animal and human populations that could tolerate such diseases and those that could not.

Indeed, diseases that pose lethal threats to humans reside all around us. Advances in medicine, sanitation, common practices for personal hygiene, communications, and institutional preparations for rapid control of disease all are responsible for the absence of epidemics threatening substantial fractions of mankind in the last 50 years. Almost surely, this collection of tools has the capacity to blunt the effect of any purposeful effort to subject large populations to deadly disease.

The main difference between the disease control task posed by natural disease and that posed by biological warfare is that the former tends to first appear with discovery of a small number of cases in a few locations, while the latter could involve near-simultaneous infection of many thousands or more people in numerous geographically separated attacks. Such an enormous challenge will only be answered by means that have been planned in advance and that can be implemented by ordinary citizens, rather than trained specialists. Viewed in this light, simple masks and warning systems that provide effective protection against any BW agent that attacks through the respiratory system are clearly very powerful tools for disease control (and BW counterproliferation), particularly in connection with other protective measures.

Contingent adoption of such a hygiene measure will be similar to relatively simple changes in behavior that humans have developed for many hundreds of years to prevent disease and its spread. By the 12th century, the Chinese had learned the value of swabbing the noses of their children with cotton rubbed in the infections of smallpox victims. By the sixteenth century, Christian ports on the Mediterranean had all learned to quarantine arriving ships for 40 days. Nomadic tribesmen of the Eurasian steppe region have long considered it bad luck to camp close to marmot colonies showing signs of sickness. Modern populations should be pleased to learn that a relatively straightforward behavioral change, based on a very simple piece of modern technology, can offer a good first step toward countering the threat of BW.

NOTES

1. A mathematical model widely employed by the US Department of Defense was used to estimate the casualty-producing effects of chemical and biological weapons. Assuming optimal weather conditions, a night attack, and agent and dissemination technology equal to the best achieved by the US, the model estimates that 0.65 kilograms of anthrax, dispersed as an aerosol along an upwind line, could cause 50% casualties over an area of 232 square kilometers. This coverage area was selected to facilitate the comparisons of the threats posed by NBC weapons that are presented later in the paper.

   An opponent could not confidently expect to bring such well-tuned agent and dissemination technologies and attack conditions together, however, and the likely conservatism of military planners suggests that somewhat heavier concentrations would be used to hedge against the possibility of less-than-expected effectiveness. Thus, we will assume that a practical estimate of the agent weight required for this attack would be 6.5 kilograms. This is still considerably less than agent requirements estimated by Steve Fetter in similar calculations. [see "Ballistic Missiles and Weapons of Mass Destruction: What is the Threat? What Should be Done?" International Security, Volume 16, No. 1, ISSN 0162-2889, Summer 1991]. It is also considerably less than the estimates one can create by scaling CW agent requirements for an equivalently lethal city attack by the ratio of anthrax to CW weights needed to create equivalently lethal volumes of air. (1/1000 for anthrax wt./sarin wt.)

2. During the time that the US maintained a program to develop BW weapons, it only required lab and production personnel to wear a simple rubber mask with a cloth filter that left the eyes and ears completely exposed. In addition, in thousands of US tests with aerosols, none produced conjunctivitis in either lab animals or humans. This past practice and experience supports our argument that attacks through the respiratory system are the significant problem.

3. In order to be effective, BW aerosol particles must be in the 1- to 5-micron size—small enough to be breathed in, but not so small as to be easily breathed out. Such particles can be removed by what are essentially fine dust filters. CW agents are normally gaseous materials that must be removed from breathing air by using activated charcoal to absorb the high boiling point vapors; they do not normally take the form of particles.

4. Prices and general technical data provided by the 3M Corporation, esp. Jeffrey Preston and Craig Colton. See "1992 POPS Catalog Reference Guide," 3M Part Number/National Stock Number, Federal Government Respiratory Protection Catalog for Department of Defense and Civilian Agencies, Worldwide Services. Information on UVEX masks was provided by Michael Fuchs.

5. Mask efficiency estimate drawn from Shu-Kang Chen, Donald Vesley, Lisa Brosseau, James Vincent, "Evaluation of Single-Use Masks and Respirators for Protection of Health Care Workers Against Microbacterial Aerosols," *American Journal of Infection Control,* Volume 22, No. 2, April 1994.

6. Estimate based on information provided by Col. William C. Patrick III, US Army (ret.), President of BioThreats Assessment, formerly director of the US Army's BW program.

7. Effective dissemination of BW agents delivered by ballistic missile requires the use of dispersible submunitions or devices for blowing aerosolized or finely ground dry agent overboard in the final moments before the missile impacts the ground. Either way, a modest fraction of the total payload weight of the missile becomes effectively disseminated agent. The BW dissemination system described in note 8, below, delivers 6.5 kg of agent with a total weight of approximately 20 kg (37% of total weight is delivered agent). Suitably quick dissemination of larger amounts of agent would require a dissemination system somewhat less heavy than suggested by scaling the total weight up in proportion to the weight of agent to be delivered. Steve Fetter (op cit) assumes that 30 kg of BW agent could be effectively delivered by a missile with a total payload weight of about 1000 kg (3% of total weight is delivered agent). For purposes of our threat comparisons, we assume a SCUD-like missile with an 800 kg payload could deliver approximately 200 kg of BW agent.

8. A commonly used "rule of thumb" for estimating potential casualties from the detonation of a nuclear weapon over a modern city is to assume that all the population within the range at which the overpressure generated by the weapon would be 6 pounds per square inch or greater would be killed, and all beyond would survive. Of course, some within this range would survive, and some beyond would die, but these two effects are assumed to be roughly equal. This rule of thumb implies that a nuclear weapon with a yield of one megaton would cause the equivalent of total destruction over an area of approximately 116 square kilometers. This estimate is probably conservative for a variety of reasons. Perhaps the most important is that it only considers the immediate effects of the weapon.

   For purposes of our calculations, we assume that a 1 megaton yield nuclear weapon would weigh 1000 kilograms. Achieving a one megaton yield in a 1000-kilogram package requires considerable technical sophistication. The US crossed this threshold in the late 1950s, and China is reported to have crossed it within the last several years. Nuclear proliferators would probably start well below this yield-to-weight ratio, as reaching it requires a design employing thermonuclear fusion, rather than all fission. Alternatively, exploitation of modern computers and weapons simulation codes, or the "reverse engineering" of a purloined Russian thermonuclear weapon, might allow quick progress to high yield thermonuclear weapons that are light enough to deliver to targets with missiles or aircraft. See Thomas B. Cochran, William M. Arkin, and Milton M. Hoenig, book by Natural Resources Defense Council, Inc., *US Nuclear Weapons Data Handbook*, volume 1, *US Nuclear Forces and Capabilities,* Ballinger Publishing Company, Cambridge Massachusetts, 1984.

Our comparisons of the relative threats posed by nuclear and biological weapons are constructed as follows. Note 1 states that 6.5 kilograms of aerosolized anthrax can cause 50% destruction of the population of an area of 232 square kilometers. This is equivalent to the 100% destruction of an area of 116 square kilometers estimated for the 1000 kilogram nuclear weapon. Dissemination of dry anthrax could be done by a system of the kind designed by the US when it had an offensive BW program. This system ground up dry cakes of agent and blew the resulting fine powder into the slipstream of a delivery aircraft. A system large enough to deliver 6.5 kilograms of dry anthrax can be built with a total weight of approximately 20 kilograms. [Estimate based on information provided by William Patrick III, cited in note 6]

Following the arguments presented in section V, we take the relative weights of weapons of mass destruction sized to do equivalent damage as an appropriate measure of the relative magnitudes of the threats they each present. Taking the magnitude of the threat posed to an unprotected city by our example nuclear weapon as 1, the relative magnitude of the threat of a BW attack against an unprotected city would thus be 1000 kilograms (the weight of the assumed nuclear weapon) divided by 20 kilograms (the weight of an equivalently destructive BW weapon) = 50.

To estimate the residual threat posed by nuclear weapons when an active defense system is present, we assume that such a defense system might be good enough to prevent significant damage by 90% of the nuclear delivery vehicles it sees. Faced with such a system, a nuclear attacker thus would have to launch an average of 10 nuclear delivery systems toward a target in order to destroy it. In this case, the residual threat posed by nuclear weapons would be 1/10th that posed by nuclear weapons against an unprotected target. If the threat posed by nuclear weapons against an unprotected city is taken as 1, the residual threat posed by such weapons would thus be 1/10th. Note that it is not unreasonable to assume that a nuclear proliferator could aspire to at least this large a weapons inventory.

9. The same mathematical model referred to in note 1 above estimates that a 1000-kg warhead delivering submunitions filled with the nerve agent Sarin could lead to 50% casualties for an unprotected population over an area of 1.47 square kilometers, assuming optimal weather conditions. Thus, matching the effects assumed for a 1 megaton nuclear weapon which, as calculated in note 8, would cause the equivalent of 100% of an area of 116 square kilometers, would require enough CW agent to destroy 50% of 232 square kilometers. This would come to 232/1.47 x 1000 kilograms = 158,000 kilograms. The relative magnitude of the threat posed by CW attack is thus 1000 kilograms (the weight of the example nuclear warhead)/158,000 kilograms = 0.0063.

   Based on tests done by the Israeli Defense Force, we assume effective attack of populations that have well-fitted chemical protective masks, and are well sheltered in buildings, would require at least 1000 times more chemical agent. If we also assume an ATBM with a 10% leakage rate, then achieving destruction equivalent to that done to an unprotected city by the example nuclear weapon requires that 1,580,000,000 kilograms of CW payload would have to be launched against the target city. This

means that the residual threat posed by chemical weapons against a city thus protected would be 1000/1,580,000 = 0.00000063.

Similarly, based on the assumed effectiveness of the various BW defenses stated in section VI, the residual threat posed by BW would be 1/100,000th of that posed by BW against a completely unprotected city, or 0.00050.

The assumed protection factor of 1000, 100 for a CW mask and 10 for a sealed shelter, is taken from: "State Comptroller Faults Gas Mask Distribution", *The Jerusalem Post* in English, 15 April 1991, p.7, cited in FBIS-NES-91-075, 18 April 1991, p. 25.

Using a lower yield-to-weight for nuclear weapons in these calculations would make CB attacks against unprotected populations appear more threatening relative to attacks with nuclear weapons. Note also that the damaging overpressures created by nuclear weapons scale down more slowly than proportional to yield. Thus, a nuclear weapon with 1/25th of the yield of a one megaton weapon would cause equivalent damage over an area that is 1/8th the size.

10. Ilan Yeshua, "Chemical Warfare: A Family Defense Manual", *The Jerusalem Post Edition*, published by the Centre for Educational Technology, printed in Israel, 1990.

11. *The Washington Post,* p. A33, October 2, 1994.

12. Training to use masks effectively is required by the US Occupational Safety and Health Administration regulations for hazardous working environments, and OSHA requires masks to be fit tested to ensure their effectiveness. Masks are tested by asking workers if they can detect a standardized sample of perfume sprayed into a covering test hood.

13. A fully effective BW mask program would include peacetime instruction on the use of a mask. It would also test the fit of available sizes of masks on individuals to identify the minority posing special fit problems and requiring tailored masks or hoods.

14. The historical information in this section is drawn from William H. McNeill, *Plagues and Peoples*, Anchor Book, Doubleday, New York, 1977.

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This paper argues that a relatively simple oro-nasal mask is the key to effective protection against large-scale biological weapon attacks. To show the efficacy of such a mask, this paper compares the threat posed by the three classes of weapons of mass destruction: nuclear, biological, and chemical. This comparison demonstrates that: a) for unprotected population the biological weapons threat may be even greater than that presented by nuclear weapons, whereas, b) for populations protected by the oro-nasal mask, the biological threat may be made several orders of magnitude less than that of nuclear weapons.

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